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Analysis of 10 years of wind vector information from QuikSCAT for the North Sea: Preliminary Results from the OREC-CA project

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Abstract

As the land space suitable for wind turbine installations is becoming saturated, the direction is turning towards offshore locations. Advantages of such sites include an increased power production, smaller environmental and social impact as well as extended availability of prospective areas. Offshore wind energy holds currently the leading role amongst renewable marine energy resources. Until recently installation of wind turbines was limited in coastal areas with maximum depth of 20 meters where sea waves start dissipating most of their energy content. Recent technological advancements allow floating wind turbines to be installed in locations with depths of 200 meters or more, thus promoting the combined use of wind and waves in common conversion platforms in order to maximize the power producing efficiency of such installations. The EU project OREC-CA (Offshore Renewable Energy Coordination Action) aims at gathering information regarding wind and wave resources in Europe, in order to develop a roadmap for research activities on this issue.

Within this context, the search for suitable sites is extended beyond shallow coastal areas, in locations where available measurements of various environmental parameters are limited. Space-borne observations are ideal due to their global spatial coverage, providing information where in-situ measurements are impracticable. The most widely used satellite observations for wind vector information are obtained by scatterometers; active radars that relate radiation backscattered from the sea surface to wind. SeaWinds, the scatterometer on board the QuikSCAT platform, launched by NASA in 1999 provided twice every day wind vector information with global coverage at a spatial resolution of 25 km, until 2009. This 10-year long dataset is utilized in the present study for the characterization of wind resources in the North Sea and the Baltic.

Keywords: wind resource assessment, offshore wind energy, renewable energy, satellite remote sensing, QuikSCAT, scatterometer, ORECCA

1 Introduction

Global climate change and its potential impact on society and the environment has lead to recent policies in order to reduce the human contribution factors. The reduction of greenhouse gas emission is one of the main goals in order to slow down the increase of the planet's temperature. The mitigation from fossil fuel to alternative, preferably renewable energy producing methods is constantly evaluated. Amongst renewable resources, wind holds currently the leading role when planning future activities.

The increased installation activities on land, a privilege of the Western societies so far, has lead to a saturation of available sites where onshore wind turbines can be installed in the future. The last decade, a shift towards offshore locations has been made and the reasons for this vary from increased power production to smaller environmental and social impact along with extended availability of such areas.

Until recently, offshore wind energy installations were typically sited in coastal, relatively shallow areas of maximum depths around 20 meters due to the high cost of foundations and connection to the electrical grid. Recent advances in floating foundations have cleared the way to installations far offshore, in depths of 200 meters or more, where the wind field is less affected by adjacent land masses. In these locations, the potential for combined wind and wave energy production arises since waves still carry all their energy content.

For such activities, knowledge of the variability of the physical parameters involved is required for all stages of siting, design and operation. In situ measurements are most desired, but they are scarce and costly. Especially for the initial stage of siting it is extremely difficult to invest in installations for in situ measurements at offshore locations.

Satellite based remote sensing techniques are gaining ground as direct and operationally feasible methods for obtaining global wind vector information amongst other physical parameters are available. Scatterometers are the most common instruments used for such purposes. Especially QuikSCAT, in orbit since 1999, recorded daily information on global wind speed and direction until 2009, exceeding by far the original plan for a 3 year mission. A descriptive overview of the progress in scatterometer applications can be found in [8].

NASA launched the polar orbiting, sun-synchronous platform QuikSCAT in July 1999. With a wide swath of 1800 km, it provided daily near global coverage of the oceans, typically with two passes depending on latitude. The SeaWinds scatterometer, on board QuikSCAT, was an active microwave radar operating at a frequency of 13.4 GHz. The principle of function was to emit radar signals towards the Earth's surface and measure the radiation backscattered from the sea surface.

The physical parameter derived was the Equivalent Neutral Wind (ENW) at 10 meters above the sea surface. This referred to the wind speed at 10 meters above the sea surface assuming neutral atmospheric stratification [7]. Parameters known to have an impact on the accuracy of retrieved information include rain, sea temperature, salinity, contaminants, large swell waves or rapidly varying winds and the atmospheric stability [5].

Long-term QuikSCAT data have been extensively and positively validated in open ocean and in enclosed seas [1, 11, 15, 12, 10], and used to map the Mediterranean and Black Sea [4]. Numerous studies have been conducted in order to compare the remotely sensed wind vector with in situ data from buoys, meteorological masts and research vessels. [3] evaluated the wind vectors observed by QuikSCAT using offshore buoy data and results indicated that the r.m.s. difference for the wind speed was about 1 ms^{-1}. For the wind direction, the r.m.s. difference was about 20^{o} when measurements higher than 3 ms^{-1} were used. In addition, there have been studies estimating the wind potential over the ocean using QuikSCAT [9, 2].

In [6] the seasonal variation of various wind related parameters was discussed. Characteristics with seasonal variation included a reduction of wind speed on the east side of the British Isles as opposed to the west coast of Denmark, likely a signature of the North Atlantic perturbations especially in winter.

For the purposes of the present study, mean wind characteristics, wind roses and wind indexes were estimated in order to obtain information regarding the variation of wind between various locations of complex morphology including semi-closed basins. Preliminary results indicated areas with average annual wind speeds of 10 ms^{-1} in the Norwegian Sea while in the Baltic, mean wind speeds did not exceed 7 ms^{-1}. The amplitude of the annual cycle is estimated at chosen locations showing the variability in different areas.

2 Data and Methods

2.1 Data

The QuikSCAT gridded data, obtained from Remote Sensing Systems (RSS, www.remss.com), were produced daily by mapping the scatterometer orbital data to a 0.25 deg longitude by 0.25 deg latitude Earth grid. For the domain of interest the grid cell size was approximately 16.83 km by 27.82 km. Overpass time was around 06:00 and 18:00 UTC, thus capturing early morning and evening conditions.

Due to the scatterometer's principle of function no wind information can be obtained over sea ice. Moreover, scatterometers are sensitive to rain because it changes the usual ocean surface and attenuates and scatters the radar energy at 13.4 GHz. Thus, RSS used contemporaneous microwave radiometer measurements for sea ice and rain detection.

Due to the ambiguity applied to the wind retrieval in the presence of rain, all relevant flags were utilized and quality control demanded that all flags show no rain for an observation to be included in the processing. To the contrary, there was no control over the sea ice mask as there was no relevant flag included in the data set.

2.2 Methods

Mean wind and data availability were estimated for the entire period of available QuikSCAT observations, extending from August 1999 until October 2009 (inclusive). Only grid cells with at least 730 rain free observations, corresponding to two rain free observations daily for an entire year, were included in the processing.

Wind directions were separated in 12 sectors where North was centred around 0°, between 345° and 15°. East was centred around 90°, between 75° and 105°, South centred around 180°, between 165° and 195° and West, around 270°, between 255° and 295°.

For the purposes of estimating the wind indexes, the period of available data was subset from November 1999 until October 2009, resulting in a round number of exactly 10 years, where all months are represented equally. The mean monthly wind index shows the variability of wind, defined as the fraction of monthly mean values over the annual mean wind speed (Eq.1).

$$IntraW.I. = \bar{U}_{month}/\bar{U} \tag{1}$$

The inter annual wind index shows the variation of wind over the 10 years of available data, as the fraction of annual mean wind over the decennial mean wind. It is estimated according to equation Eq.2 [14].

$$InterW.I. = \bar{U}_{year}/\bar{U} \tag{2}$$

3 Results

Figure 1 shows the number of rain free wind observations retrieved from QuikSCAT during the period of 10 years. This corresponded to 3745 calendar days but data were available only for 3733 days. If all available days had rain free observations for both morning and afternoon passes, it would account for a maximum of 7466 rain free observations for a given grid cell. The maximum number of rain free observations recorded was 7085, accounting for 94.9% maximum data availability. Coastal areas and semi-enclosed, shallow basins of complex coastal morphology were masked out due to a land mask, thus no wind information was available there.

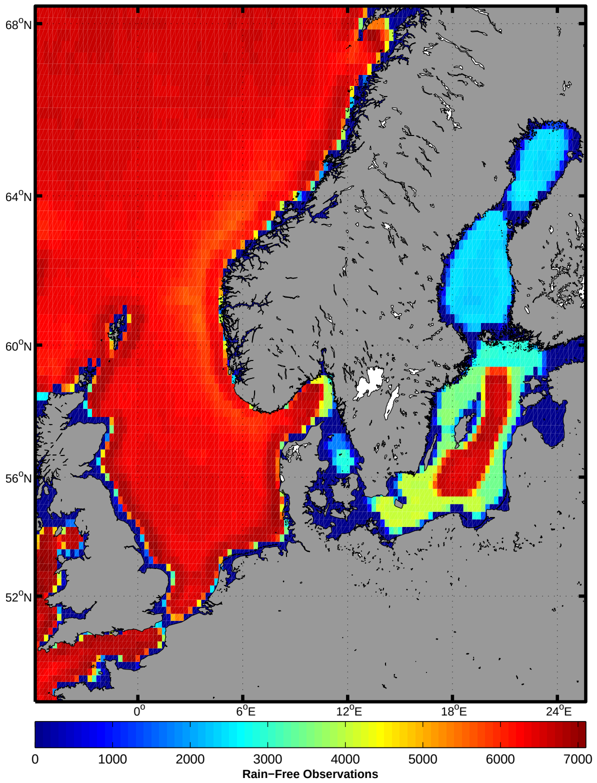

Figure 1: Rain free data availability from QuikSCAT for August 1999 until October 2009. Dark blue areas indicate zero wind retrievals. Maximum available observations for a grid cell was 7085.

The northern Baltic Sea, including the Gulf of Bothnia, was under-observed with a maximum of 3000 observations. The central part of the basin was very well observed through the years, with a maximum of 7000 recorded observations. That was not the case for the greatest part of the coastal areas, the Danish Straits and Kattegat where only a maximum of 4500 observations was recorded. This was an impact of the ice mask implemented from November or December until April and even May in some areas. The North Sea and eastern North Atlantic were very well observed during the years with the exception of coastal areas extending approximately 50 km offshore.

Figure 2 shows the mean wind computed from all available QuikSCAT rain free observations and estimated only for the grid cells with at least 730 rain free observations. Wind speeds range from a minimum of 6 ms^{-1} observed for the Gulf of Bothnia, in the Baltic Sea to a maximum of 10 ms $^{-1}$, observed in the eastern North Atlantic between Norway and the Shetland Islands. A strong lee effect was present in the western North Sea and the Irish Sea, caused by the British Isles and Ireland, respectively. A strong channelling effect was observed in the North side of the English Channel, offshore from Belgium and southern Netherlands.

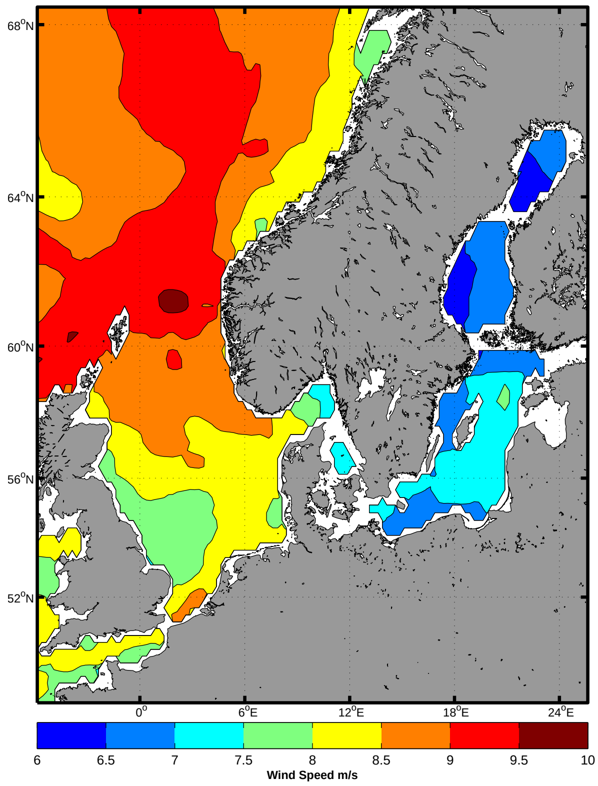

Figure 2: Mean wind from QuikSCAT for the period August 1999 until October 2009. Only grid cells with at least 730 rain free observations were included in the analysis.

In general higher wind speeds were observed in the West compared to the East and to the North compared to the South parts of the domain. Highest speeds were recorded in the eastern North Atlantic and the northern North Sea, while lowest speeds in the Baltic Sea. A gradual reduction of wind speed was observed when approaching the eastern part of the Norwegian Sea, especially around the Lofoten archipelago. In the eastern North Sea, a decrease in wind speed was observed between the northern part of Frisia and the northern part of the Heligoland Bight in the German Bight. This could not be associated with lee effects due to the area's exposure to the dominant south-westerly winds.

Figure 3 shows the spatial variation of wind roses from 10 years of QuikSCAT observations at different locations, with at least 1 year of two observations per day. The variation of wind roses from offshore to coastal areas is well captured. There is consistency with the expected results as wind rose distributions vary according to the orographic features. A strong channelling effect was observed in the English Channel and in the central Baltic Sea. In the North Atlantic when approaching the Norwegian coast, the wind rose distributions adapt to the coastal morphology since the main wind direction was aligning parallel to the coast. However, the wind roses along the Norwegian North-West coast showed a strong land component, likely due to a Bora like type of wind. Bora is a north-easterly strong and cold wind common in the Adriatic Sea. It is classified as an orographic or katabatic wind [4].To the contrary, this feature did not appear in the South-Western part of the Norwegian coast.

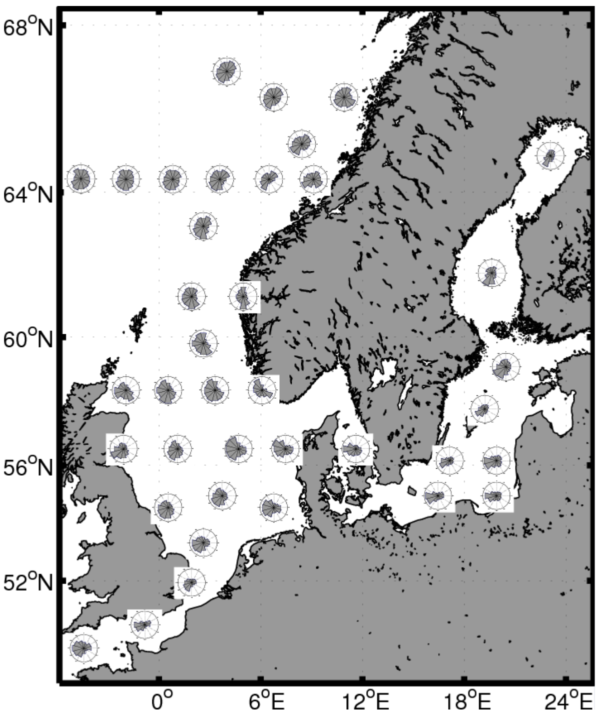

Figure 3: Wind roses for various locations in the domain.

Within the OREC-CA project, locations are sought where platforms utilising combined wind and wave energy resources can be installed. Figure 4 shows the locations of existing measuring platforms, from which in situ observations regarding waves and wind can be retrieved in order to validate the remotely sensed information from satellites. In the present study, mean monthly and inter annual wind indexes were estimated using observations from QuikSCAT. In the future, in situ measurements from the locations shown will be used to estimate inter and intra annual wind indexes and compare them with the QuikSCAT derived ones.

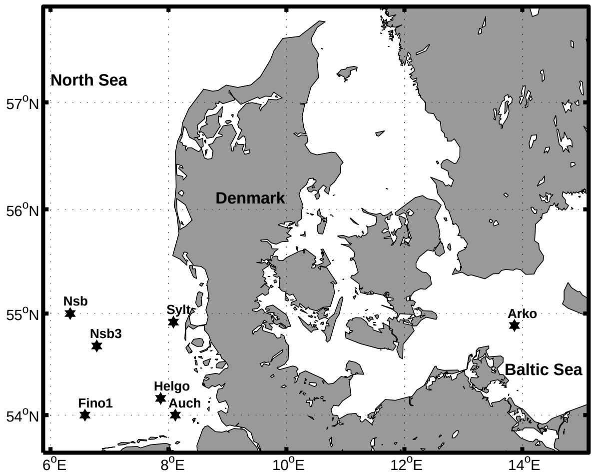

Figure 4: Locations of experimental sites, with platforms and buoys were combined wind and wave energy production may be accomplished. Wind indexes from in situ measurements will be compared with the QuikSCAT derived ones.

Figure 5 shows the mean monthly wind index for seven locations in the eastern North Sea (Frisia) and the south-western Baltic Sea. All locations exhibit similar monthly variations, with highest index values in November, December and January. A constant decrease from February was observed and minima were reached during April and May. An abrupt increase was noted during June for all locations, followed by lows in July and August. Maximum values exceeded 1.3 in the North Sea.

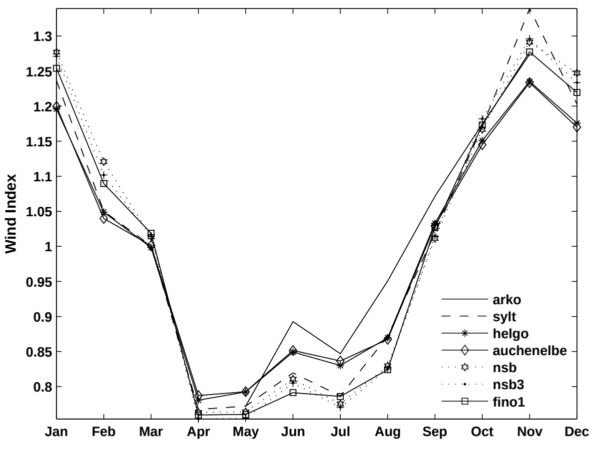

Figure 5: Mean monthly wind indexes derived from QuikSCAT, using rain free observations from November 1999 until October 2009.

The inter annual wind indexes, presented in Figure 6, show variable conditions between locations. Areas in the North Sea exhibit a more consistent pattern, with the year 2003 marking a minimum and 2008 a maximum in wind index values. The single location in the Baltic Sea exhibited higher index values 2002 to 2004, when compared with the locations in the North Sea. From 2004 and afterwards it suffered a drastic decrease when all locations in the North Sea were undergoing increase in index values. Only during 2007 and onwards did the pattern normalise and follow the behaviour of the North Sea locations.

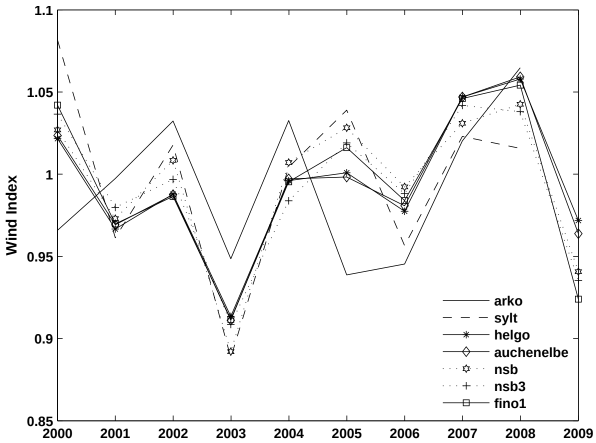

Figure 6: Inter-annual wind indexes derived from QuikSCAT, using rain free observations from November 1999 until October 2009.

4 Discussion

In the present study, ten years of observations from QuikSCAT were utilised in order to evaluate the wind climatology in the North Sea and the Baltic Sea. The main purpose was to identify locations with a high wind energy production potential that can be combined with wave energy production platforms in the future. For this, long term satellite observations of extended spatial coverage provided an excellent basis for a preliminary analysis in large areas, far offshore where in situ measurements would be either impossible to obtain or of extremely high cost.

It was shown that the greatest part of the domain was covered on average 85% of the time. QuikSCAT results may be considered representative in these areas. The reduced data availability in the coastal areas of the Baltic basin generates a bias towards spring and summer conditions due to the sea ice mask that was applied during winter.

Mean wind speeds were found consistent with expected results, showing increase values in offshore areas and a decrease in closed, well protected basins or behind land masses that create strong lee effects. The part of the eastern North Sea with reduced mean wind speeds that could not be attributed to lee effects due to the exposed nature of the location may be an artefact from the scatterometer due to strong tidal phenomena in this area that result in frequent exposure of the tidal flats and lack of water coverage.

Another explanation may be related to atmospheric stability, with frequent stable conditions leading to an underestimation of the wind speed from QuikSCAT. As discussed in [13], the stability conditions in the Horns Rev wind farm, in the Danish part of the North Sea, were found were most often neutral or unstable. In [17] it was found that for the German Bight, the stability conditions around the FINO-1 meteorological mast were neutral 50% of the time, unstable 34% and stable only 16% of the time. It seems that the frequency of stable atmospheric stratification in the region can not account for this reduction in wind speed.

The main wind directions in the North Sea followed very well the known dominant Westerlies and South-Westerlies. The adaptation of the wind field due to the coastal morphology was very well represented even between complex land masses, such as in the English Channel and the South Baltic Sea.

Mean monthly wind indexes showed a constant decrease from January until April and a sudden increase during May and June. This is consistent with similar results from the Mediterranean, where [4] found the same pattern especially for the North-West Mediterranean with a shift of one month towards the summer. There, the mean monthly wind index was minimum in June and exhibited an increase during July and August. The range of values was also found similar varying between 0.75 and 1.4 in both cases.

Inter-annual wind indices indicated that especially the years 2000, 2005, 2007 and 2008 had particularly high winds compared to the decennial means. In the results of [4], 2003 was an exceptionally windy year but for the various locations in the North Sea, this was not the case. The maximum range of values was found slightly different for the North-West Mediterranean, reaching 1.15 while in the case of the North Sea maximum values did not exceed 1.07.

5 Conclusions

QuikSCAT data provide a reliable representation of the wind regime in the North Sea and the Baltic Sea. The wind direction distributions adapted to the coastal morphology but also reflected specific coastal wind regimes. i.e. sea-land breezes or orographic Bora like regimes. The dominant directions were found to be the Western and South-Western ones. A profound channelling effect was identified, with wind entering in the North Sea through the English Channel. Moreover, intense lee effects were triggered by the British Isles. Most coastal areas of the Baltic Sea were under observed due to the sea ice mask. Intense lee effects triggered by the British Isles were identified. It has been shown that the inter-annual wind variability is slightly lower in the Northern European Coastal Seas when compared to the Mediterranean basin. Moreover, strong anti-correlation between the two basins was found, revealed by the inter-annual wind indexes.

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